

Opera and Poison - A Secret and Enjoyable Approach to Teaching and Learning Chemistry

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Abstract

The storyline of operas, with historical or fictional characters, often include potions and poisons. This has prompted a study of the chemistry behind some operatic plots. The results were originally presented as a lecture given at the University of Minho in Portugal, within the context of the International Year of Chemistry. The same lecture was subsequently repeated at other Universities as a invited lecture for science students, and in public theaters for wider audiences. The lecture included a multimedia and interactive content that allowed the audience to listen to arias and to watch video clips with selected scenes extracted from operas. The present paper, based on the lecture, not only demonstrates how chemistry and opera can be related, but may also serve as a source of motivation and inspiration for chemistry teachers looking for alternative pedagogical approaches. Moreover, the lecture constitutes a vehicle that transports chemistry knowledge to wider audiences through examples of molecules of everyday life, with particular emphasis on natural products.

Introduction

Opera is a stage art form where music and theater meet and its stories and characters, if adequately exploited, can constitute an effective vehicle to bring chemistry to students, and to an even a broader public. The creation of bridges between art and chemistry is a well known and experimented pedagogical strategy.^{1,2} For similar purposes chemistry and music have also been compared and combined.³⁻⁵ Recently a chemical and forensic view of Shakespeare's tragedy "Romeo and Juliet" has been reported in this journal.⁶

There are a few very obvious connections between opera and chemistry, one being Alexander Borodin (1833-1887), better known nowadays for his opera "Prince Igor" (1890) despite the fact that in his time Borodin was a highly considered chemist who, among other discoveries, described the aldolic condensation.⁷ An even more direct connection between opera and chemistry is the comic opera "Iono and Faradette", based on a manuscript by D. C. Long, a student at Yale, and music by Dr. J. A. Timm. The première (also *dernière*?) was in 1923 on April 3 at the Yale Dining Hall at a Smoker of the American Chemical Society. The opera's *dramatis personae* are Feodor, an alchemist in quest of the elixir of life; Ompitor, the spirit of the greatest of all alchemists; Iono, the prince of the ions; Faradette, the princess of electricity; Natia, the elixir of life; Mortus, death; sodium and chlorine atoms, and organic molecules. The opera includes several ballets with names like "The Dance of the Salt Molecules", "Ionic Equilibrium", "Electrolysis" and "Dance of the Organic Molecules".⁸

While these direct connections between opera and chemistry exist, a more common relation lies with the use of potions and poisons in opera, often introduced to support stories of passion and romance. Following this theme, the chemical content of several opera stories has been analyzed and presented in a lecture originally delivered to a mixed academic audience (mainly consisting of chemistry and biochemistry students

and staff) at the University of Minho, Portugal, in the context of the International Year of Chemistry. The operas that fulfilled this purpose have been classified according to four main categories: “apothecary operas”; “operas of poisonous natural products”; “operas of the great poisoners of Antiquity” and “arsenic operas”. A very recent opera inspired on Marie Curie is also discussed. The chemical content of the analyzed operas is shown in Table 1.

The apothecary operas

The lecture starts with the description of four “pharmacy operas” that illustrate how the work of chemists and pharmacists in the 18th and 19th centuries had an impact on the art world. Carl Wilhelm Scheele (1742-1786) from Sweden was a practicing pharmacist and chemist who made a remarkable contribution to the development of chemistry with his discovery of seven elements: O, N, Cl, Ba, Mn, Mo and W (oxygen was almost simultaneously discovered by Scheele, Priestley and Lavoisier); the identification of gases such as HF, H₂S, SiF₄ and HCN; and the preparation and characterization of many organic compounds (glycerol and the benzoic, oxalic, tartaric, prussic, mucic, citric, gallic, pyrogalllic, lactic and uric acids). Scheele was also the first to synthesize copper arsenite (CuHAsO₃), a green compound that became a much sought after pigment in the Victorian period and was designated as “Scheele’s green”.^{9,10} Coincidentally (or perhaps not!) when Scheele was in Stockholm performing his first studies with relevance to chemistry, Joseph Haydn composed “Der Apotheker” (1768), a comic opera where Mengone, a pharmacy apprentice, exalts the gastric virtues of rhubarb and manna. Rhubarb is a plant that owes its purgative and laxative properties to a high content of oxalic acid.¹¹ Manna, formerly used for the same purposes, is a sweet extract obtained from the sap of the tree *Fraxinus ornus* (its name was given in medieval times by analogy with the biblical manna, the food offered by God to the

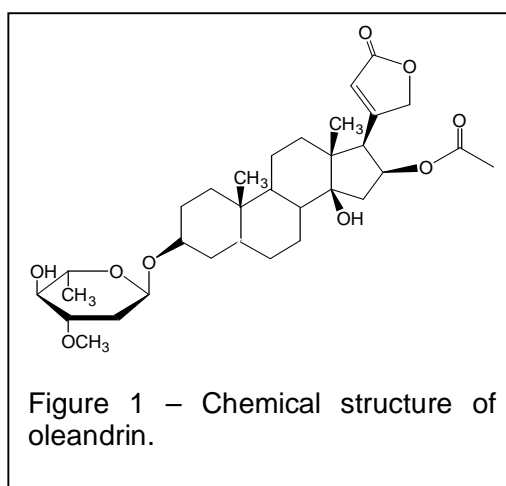
Israeli people on the way to the Promised Land). Compounds like mannitol and mannose owe their names to manna.¹² A few years after "Der Apotheker", Carl Ditters von Dittersdorf composed "Doktor und Apotheker" (1786) an opera which, as the title suggests, also has a plot with a pharmacist as main character. Luigi and Federico Ricci's "Crispino e la Comare" (1850), known in English as "The Cobbler and the Fairy" is another opera with a pharmacist (Mirabolino) in the cast. Act I takes place in a Venetian square where, among others shops, an apothecary sells his wares.

Nevertheless the best example of an apothecary opera is probably "Il Campanello" (1836), by Gaetano Donizetti, which includes the sound of a bell in the overture ("campanello" is the Italian word for bell.) This is one of the most comical operas of the Italian repertoire of 19th century. Its plot is centered on Don Annibale Pistacchio, a wealthy pharmacist of advanced age who just married Serafina, a beautiful young woman. Enrico, Serafina's former fiancé, jealously decides to ruin their wedding night by keeping Don Annibale out of the bed. The pharmacy's bell will be heard each time Enrico, always under a different cover, visits the pharmacy to present to Don Annibale the most complicated medical prescriptions. In the aria "La Povera Anastasia", a rather humorous moment, Enrico, disguised as an old man, describes the endless diseases of his poor wife Anastasia. He then gives to Don Annibale an endless prescription that requires the most incredible components (some of them actually in pharmaceutical use at that time!). The audience listens to the "prescription duet" while the list of ingredients is projected. Some of these ingredients are referred by their alchemic names: *butirro d'antimónio* (antimony(III) chloride) and *etiope minerale* (mercury(II) sulfide). The prescription also includes many plants and "specialties" such as sulfur, pumice, frogs, vomiting manna and castor oil!¹³

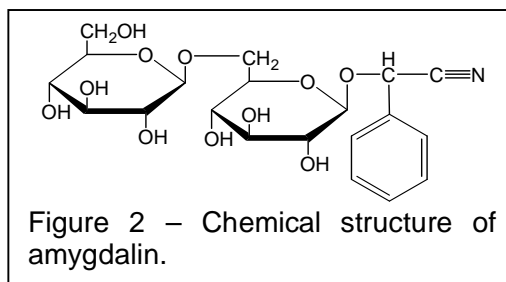
The operas of poisonous natural products

As mentioned previously, many operas contain references to poisons that give them a direct link with chemistry. In addition, many of these poisons are natural products whose chemical structures are known.

“Suor Angelica”, the one act opera from Puccini's “Il Trittico”, presents a paradigmatic plot in terms of poisons. The libretto's author, Giovacchino Forzano, obviously had a considerable knowledge of pharmacognosy. In the story that takes place in 17th century Italy, Sister Angelica has been isolated in a convent for several years. The day she learns that her young son, whom she had not seen since his birth, has died, she decides to put an end to her life (audience watches a video clip with the scene of Angelica preparing and drinking a concoction of herbs - aria “Amici fiori”). While collecting the plants Angelica names them one by one: oleander, laurel cherry, hemlock and belladonna. Oleander (*Nerium oleander*) is a very toxic mediterranean plant. Its toxicity is due to oleandrin (Figure 1), a cardiac glycoside that inhibits sodium-potassium adenosine triphosphatase ^{14,15}

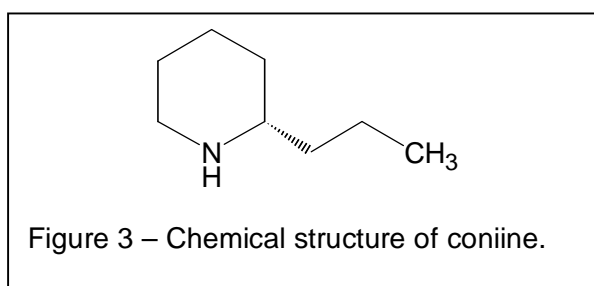


Cherry laurel (*Prunus laurocerasus*) is rich in amygdalin, a cyanogenic glycoside (Figure 2).

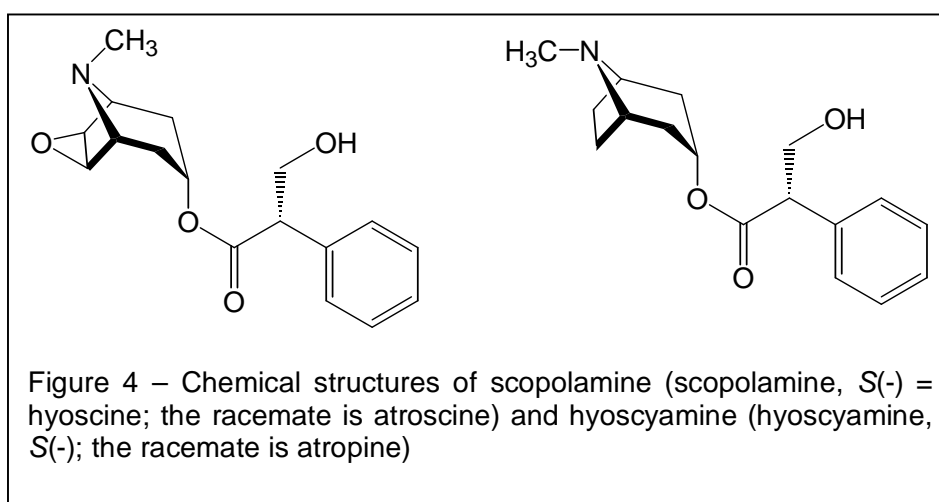


When ingested it releases cyanide into the bloodstream, diverting the use of oxygen by cells due to the inhibition of cytochrome $a-a_3$ oxidase, and reducing dramatically the formation of adenosine triphosphate.^{16,17} Currently there are several cyanide antidotes; for instances an injection of sodium nitrite (NaNO_2), immediately followed by another of sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3$). Nitrite oxidizes hemoglobin's Fe(II) to Fe(III) creating a controlled level of methemoglobin. Cyanide has high affinity for Fe(III) and binds preferently to methemoglobin forming cyano-methemoglobin. Thiosulphate in turn converts the cyanide into thiocyanate, a compound with low toxicity and rapid renal excretion. Alternatively there is a treatment with hydroxocobalamin (vitamin B_{12a}), based on the replacement of its OH^- group by CN^- . The reaction of hydroxocobalamin with CN^- results in the production of cyanocobalamin (vitamin B_{12}) which is benefic for the body^{18,19}

Hemlock (*Conium maculatum*) always brings to mind Socrates, the Greek philosopher condemned to death by ingestion of a potion made from this plant. The active ingredients of hemlock are piperidinic alkaloids and among them coniin is the most toxic (Figure 3), being responsible for muscle paralysis, with death resulting from asphyxia. There is no antidote for coniin but continued artificial ventilation of the victim during several days has been successfully used in these cases.²⁰

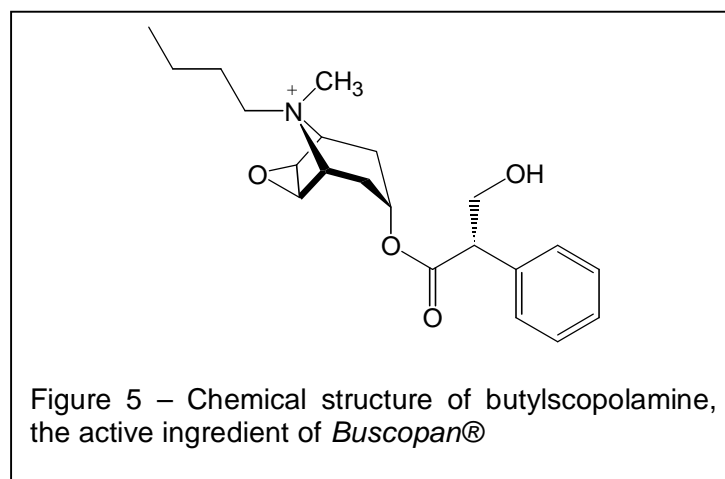


Belladonna (deadly nightshade) is another well-known poison. Let us first analyze its Latin name, *Atropa belladonna*. The term *Atropa* derives from *Atropos*, the mythological Greek goddess responsible for cutting the life thread; *Belladonna* refers to the fact that 17th and 18th century Venetian ladies used to apply the juice of its berries to their eyes. This causes dilation of pupils and consequently the eyes can appear brighter and apparently more beautiful (at the expense of blurred sight!).^{21,22} Belladonna belongs to the *Solanaceae* family which, among others, includes *Solanum dulcamara* (bittersweet), *Datura stramonium* (devil's trumpet), *Hyoscyamus nigery* (henbane) and *Mandragora officinarum* (mandrake).²² All these plants contain high concentrations of anticholinergic tropanic alkaloids such as scopolamine and hyoscyamine (Figure 4).



These molecules exhibit optical isomerism and biologically the most active form is the levorotatory isomer (-) that preferentially binds to the acetylcholine receptors inhibiting the action of this molecule. Comparatively, hyoscyamine has predominantly exciting properties while scopolamine has mainly relaxing and hallucinogenic properties.^{23,24} By adding a butyl cgroup to the tropanic nitrogen atom, chemists were able to make these molecules less active to the brain and central nervous system because the resulting

butylated form cannot cross the blood-brain barrier. In the case of scopolamine this form corresponds to a well known anti-spasmodic drug (Figure 5): *Buscopan*, *Buscozol*, *Buscapina*, (depending on the country).²⁵



The libretto of Wagner's opera "Tristan und Isolde" (1865) has been analyzed in a very interesting medical article. The author argues that Tristan and Isolde's symptoms, after having ingested the love potion, are consistent with an anticholinergic syndrome due to psychotropic drugs such as *Solanaceae* tropanic alkaloids (audience listens to "Am Obermast die Segel ein" from Act I while observing a table with the symptoms described in Wagner's *libretto* compared to the clinical symptoms of an intoxication with *Solanaceae* which, among others, include tachycardia, flush, hyperthermia, blurred vision, desorientation, pupillary dilatation, photophobia, coma, visual and auditory hallucinations and death).²⁶

Shakespeare's plays, many of which were subsequently converted into operas, are rich in poisoning plants. In his tragedy "Hamlet" one of these plants precipitates the plot when the ghost of Hamlet's father tells his son how he has been assassinated by his uncle who had poured henbane (another *Solanaceae*) extract into his ear while he was asleep. The French composer Ambroise Thomas was inspired by this play for his opera

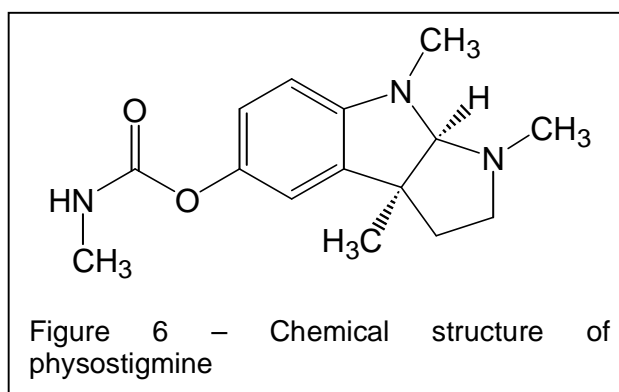
"Hamlet" (1868), which in Act IV contains the famous Ophelia's mad scene.

In "Romeo and Juliet" in Act IV, scene 3, Juliet refers to the cries of mandrake, which is also a *Solanaceae* ("*Shrieks like mandrakes torn out of the earth*")²⁹ making us wonder whether she knew the actual composition of Friar Laurence's potion which would make her appear to be dead, avoiding thus to marry Paris (audience watches a video clip with the aria "Dieu! Quel frisson court dans mes veines?" - the "poison aria" - of Charles Gounod's opera "Romeo et Juliette" (1867). In this scene from Act IV, Juliet is about to take the potion and wonders what she will feel and imagines the horrors of waking up later on in the mortuary chamber).

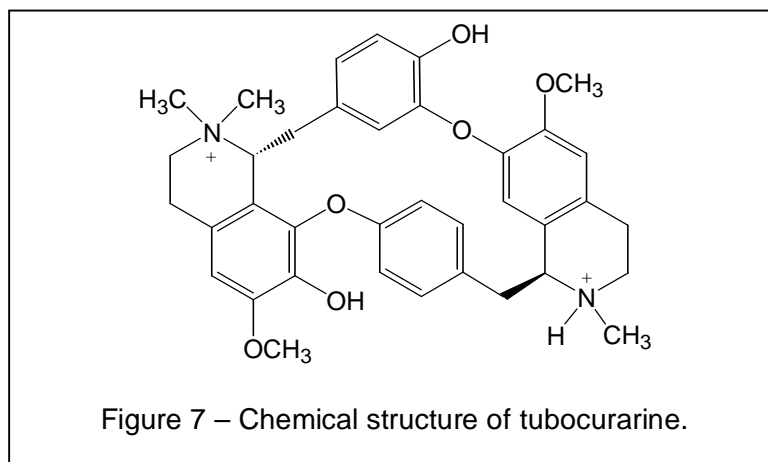
In medieval Europe mandrake was considered a plant with special powers. Witches applied an ointment made with fat and extracts from this plant and other *Solanaceae* in the underarms and other parts of the body. The state of excitement and hallucination they attained would make them believe they could fly on brooms and cast spells.²⁷ The skin is in fact an appropriate route for the introduction of hyoscine-like compounds into the body.²⁸ The anthropomorphic aspect of mandrake's root also contributed to its reputation as a magical plant being believed that those who snatched the mandrake out of the earth would become deaf or crazy with the screams it would release. In Léo Delibes's opera "Lakmé" (1883), Lakmé uses *Datura stramonium* (also a *Solanaceae*) for her suicide. The opera is primarily famous for the Act I duet "Viens, Mallika" (known as the "Flower Duet", which is played to the audience).

Meyerbeer's opera "L'Africaine" (1865) is very loosely inspired on the life of the Portuguese navigator Vasco da Gama who, in this story, is loved by Selika, an Indian slave, formerly a queen. When she accepts that her love is hopeless, she commits suicide by inhalation of the vapors of the manchineel tree (*Hippomane mancinella*), one of the most toxic existing plants (audience listens to the aria "O Paradis" from "L'Africaine"). Manchineel is a large tree that contains many toxic compounds. Among

them is physostigmine (Figure 6), an acetylcholinesterase inhibitor alkaloid that causes the paralysis of muscles with subsequent respiratory and cardiac failure.³⁰ Most probably Caribbean Indians have certainly used extracts of manchineel to poison the tips of their arrows.³¹



"Il Guarany" (1870) is an opera composed by Antônio Carlos Gomes, a Brazilian composer much admired by Giuseppe Verdi. The story takes place in Brazil, somewhere in the Rio de Janeiro's region, in the 16th century. Its characters include Portuguese colonizers, Spaniards and two rival Indian tribes. There are victims of arrows, probably tipped with poison and, Pery, the main character, in Act III takes a poison and its antidote (the audience listens to the beautiful overture of the opera). The use of plant poisons in this opera should not be surprising considering that it takes place in a country with a rich and varied flora. Curare is the common name for the poisons used on the arrow tips of South America's Indians, consisting of a blend of toxic natural compounds of intense and lethal paralyzing action. One of the most important of these ingredients is tubocurarine (Figure 7), an alkaloid that acts as muscle relaxant and belongs to the category of non-depolarizing neuromuscular-blocking drugs; it is used in anesthesia to cause muscle relaxation during surgery.^{32,33}



The operas of the great poisoners of Antiquity

Some operas include historical characters that are known for having been experts in manipulating poisons. Cleopatra (69-30 BC) is often considered one of the first experimental toxicologists due to her habit of testing different poisons on poor and sick people, with the excuse of treating them. According to the legend she chose to commit suicide with a poisonous snake.^{21,34} Samuel Barber's opera "Antony and Cleopatra", composed for the inauguration of the new Metropolitan Opera House in 1966, is an appropriate vehicle to introduce the topic of snake venom. Venom is a complex mixture of neurotoxins that includes proteins, lipids and sugars causing destruction of the victim's tissues, weakness of the muscles, paralysis, difficulty in breathing, destruction of blood cells, and damage to the cardiovascular and coagulation systems³⁴ (audience listens to Act III's aria "Give me my robe" which precedes Cleopatra's suicide).

Mithridate VI (132-63 BC), king of Pontus, Turkey, also deserves a place in the gallery of the great poisoners of history. Fearing death by poisoning he tested various poisons and antidotes on his prisoners. The legend says that this led him to the discovery of a universal antidote, known as *Mithridatium* (which was composed of over sixty ingredients, mostly of plant origin, ground and taken up in honey). Still according to the

legend, after having been defeated by the Romans, his antidote's formula was taken to Rome where it was perfected by Andromachus, one of Nero's physicians. The resulting new antidote became known as *Theriaca Andromachi*, and was used until the 18th century (more recent versions included dried flesh of vipers).^{35,36} According to Jean Racine's play "Mithridate" (1673), when the king of Pontus was defeated by the Romans he attempted suicide by poisoning but having had throughout his life taken non-lethal doses of various poisons, was consequently immune. This phenomenon of self immunization is nowadays known in toxicology as *mithridatism*.³⁷ In "Mitridate, Re di Ponto" (1770), the opera that Mozart composed at the age of 14, one finds Mithridates in Act III giving to Aspasia a cup of poison as he considers that she was unfaithful to him. Aspasia wonders if she has enough courage to drink the poison and wishes that she could get back to her beloved Sifare, the son of Mithridates (audience watches a video clip with Aspasia's aria "Ah ben ne fui presaga...Pallid' ombre"). Mozart's own death is wrapped in a certain mystery and, accordingly, several explanations have been suggested, including poisoning by his rival Salieri. Pushkin's play "Mozart and Salieri" (1830)³⁸ and the homonymous opera of Nikolai Rimsky-Korsakov (1898), helped to spread this idea. More recently, Milos Forman's movie "Amadeus" (1984) also contributed to this belief.

In ancient Rome there were schools where the art of manipulating and administering poisons was taught. Agrippina the Elder (14 BC – 33) has been one of the Roman personalities to whom the power of poisons most appealed. She used them widely in order to achieve her political and personal goals. She poisoned her first husband in order to marry Claudius, the Emperor and her uncle. Many intrigues, and probably several poisoning events later, she managed to place her 16 year old son Lucius (from her first marriage) on the throne of Rome, under the name of Nero.³⁹ Despite all the atrocities, Georg Friedrich Handel's opera "Agrippina" (1709) portrays this luminary in a

quite sympathetic light.

The arsenic operas

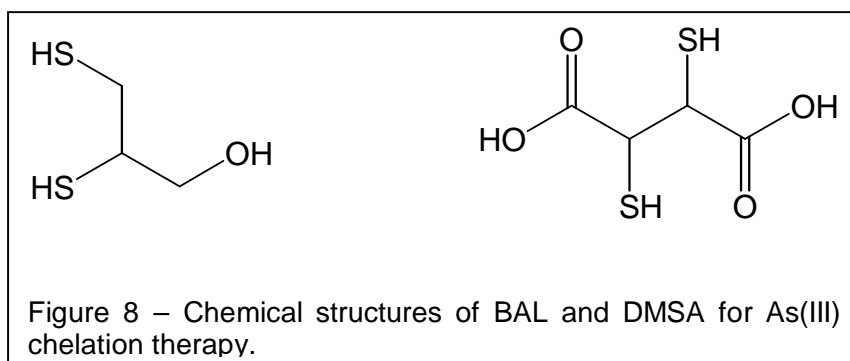
Early in the dawn of mankind, arsenic minerals such as realgar (As_4S_4), orpiment (As_2S_3) or arsenopyrite (FeAsS) were found to be a threat to health. It certainly didn't take long to discover that these sulfides, upon heating, could generate the even more poisoning As_2O_3 . Unlike the sulfides, the trioxide is soluble in water affording a colorless solution.⁴⁰ Giuseppe Verdi's masterpiece "Simon Boccanegra" (1857) is an opera inspired on Simon Boccanegra, the first Doge of Genoa. Boccanegra was assassinated in 1363 possibly with arsenic trioxide (audience watches a video clip with Act II's scene of "Simon Boccanegra" where the Doge drinks the water poisoned by his political enemies).

Arsenic is a semi-metal of group 15 with two oxidation states: As(III) and As(V); its toxicity is mainly due to the high affinity of As(III) for thiol bearing biomolecules and possibility due to the fact that As(V) might replace phosphorus in phosphates.⁴¹ Despite its toxicity, 2400 years ago compounds of this element were already part of traditional Chinese medicine. The western world also found some therapeutic uses for arsenic, including its application as a component of Fowler's solution in 1785, used as a cure for all kinds of diseases. *Salvarsan*, Paul Erlich's drug that appeared in 1909 for the treatment of syphilis also contained arsenic.^{40,42}

The most famous, and infamous, practitioners of the art of poisoning in 15th century Italy have been Cesare Borgia and his sister Lucrezia (1480-1519). The Borgias created a fatal arsenic trioxide-based potion that often was put in the wine offered to certain guests. It is believed that their father, Pope Alexander VI, ironically died after having drunk by mistake the laced wine intended for another victim.²¹ (The audience watches a video clip of the end of Act I of Donizetti's opera "Lucrezia Borgia" (1833)

showing Gennaro drinking the poisoned wine given to him by his mother's husband; afterwards Gennaro is forced by his mother to take an antidote which she also supplies).

Chelation therapy is currently the treatment performed in cases of arsenic intoxication, which requires that thiol bearing chelating agents are given to the patients. Upon chelation of As(III) ion there is a faster excretion of this element from the body. 2,3-dimercaptosuccinic acid (DMSA) given orally and the intravenously administered BAL (2,3-dimercaptopropanol are examples of such chelating agents (Figure 8).⁴³



"Scheele's green" from its discovery (1775) has found application as a pigment for coloring a wide variety of materials, in particular wallpaper, due to its beautiful shade and, very importantly, its low price. In 1870 in England an estimated 30 million rolls of wallpaper were produced, and four out of five of these papers contained arsenic. Many of the patterns were designed by William Morris (1834-1896), one of the pioneers of the "Arts and Crafts" movement and the main shareholder of the biggest arsenic mine in England. The widespread popularity of the green wallpaper fashion soon came to an end with the news that people living in moist houses lined with these papers, were getting sick and dying.⁴⁴ In 1891 the Italian chemist Bartolomeo Gosio conducted a research project that partially solved the mystery: there was a poisonous gas evolved by rotten wallpaper painted with arsenic salts. The gas in question would only be

correctly identified in 1932 by the English chemist Frederick Challenger as being trimethylarsine, $\text{As}(\text{CH}_3)_3$ (Figure 9). The mechanism by which some micro-organisms can promote the methylation of arsenic was first described in 1971.⁴⁵

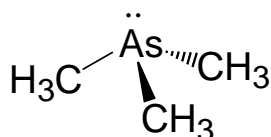


Figure 9 – Chemical structure of trimethylarsine.

Gilbert and Sullivan's comic opera "Patience" (1881) is a satire on the 19th century European art movement which emphasized aesthetic values over moral and social themes in art, literature and design. Gilbert libretto includes a reference to the "Sheele's green" and other arsenic greens:

"I do not care for dirty greens

*By any means"*¹³

The opera of the International Year of Chemistry

In 2011 at the UNESCO headquarters in Paris, as part of the celebration of the centenary of the attribution of the Nobel Prize in Chemistry to Marie Curie and the International Year of Chemistry, "Madame Curie" the opera composed by the Polish musician Elżbieta Sikora premiered. One of the opera characters is the incredible Loïe Fuller, an American dancer who created a remarkable public impact in Paris in the early years of the 20th century. She was a fascinating personality who blended art with science and technology. Fuller created and patented revolutionary techniques of stage lighting and special effects. For her performances she employed luminescent salts in the stage decors and even in her garments. The resultant glowing effects fascinated the audiences. The discovery of radium by Marie e Pierre Curie impressed her so much

that she tried to obtain a sample for use in her 1904 "Dance of Radium".⁴⁶

Conclusions

Some opera storylines have been studied in the light of their potential chemical content (Table 1). Emphasis has been given to chemical, toxicological, pharmacological and historical aspects. The results of this research were originally presented as a lecture delivered to an audience mainly consisting of chemistry and biochemistry students, as part of the commemorations of the International Year of Chemistry.

From the very beginning this project seemed to have potential to interest science students but, in a quite unexpected way, it was found to have an even broader impact: apart from soliciting interest at several universities throughout the country, the same lecture also has been enthusiastically received by the general public (museums, theaters) and also recorded and broadcasted on the Portuguese classical radio station (Antena 2).

This paper, which is based on that lecture, aims above all at proposing an alternative and pleasant (light?) way to approach chemistry. In the classroom context this content can encourage, inspire and motivate teachers to use a similar strategy. For example, the opera "Suor Angelica" ("The operas of poisonous natural products") can be very helpful in Bioinorganic Chemistry classes for undergraduate students when studying the interaction of strong π -acceptors (CN^- in particular) with iron containing biomolecules such as hemoglobin and cytochrome $a-a_3$ oxidase. This operative approach of chemistry also constitutes a good opportunity to address some history of chemistry and science.

The lecture usually ends with a quiz (available in the Supporting Information), projected for the audience. A choice of four answers is provided for each question and, if necessary, the molecular structures of the compounds involved are shown. The

answers have been provided orally after the quiz although a different model might be exploited. Even when presented to a wider public this quiz is interesting as it gives participants the opportunity of discovering, through a musical connection, some molecules of everyday life including caffeine, nicotine, morphine or ethanol. This is always beneficial in contributing to the public understanding of Science and motivating interest in Chemistry.

Table 1 – Materials and chemical compounds and respective opera scenes

Materials & Compounds	Opera	Aria/Scene
Rhubarb /oxalic acid Manna / mannose; mannitol	“Der Apotheker”(Haydn)	"Per quel che ha mal di stomaco"
Antimony(III) chloride Mercury(II) sulfide Sulfur Manna Castor oil / ricinoleic acid	“Il Campanello” (Donizetti)	Prescription duet
Oleander / oleandrin Cherry laurel / amygdalin Hemlock / coniine <i>Atropa belladonna</i> / scopolamine and hyoscyamine	“Suor Angelica” (Puccini)	“Amici fiori”
<i>Solanaceae</i> / scopolamine and hyoscyamine	“Tristan und Isolde” (Wagner)	“Am Obermast die Segel ein“
Henbane / scopolamine and hyoscyamine	“Hamlet” (Thomas)	
Mandrake / scopolamine and hyoscyamine	“Romeo and Juliet” (Gounod)	Poison aria
<i>Datura stramonium</i> / scopolamine and hyoscyamine	“Lakmé” (Delibes)	“Viens Malika” (Flower duet)
<i>Hippomane mancinella</i> / physostigmine	“L' Africaine” (Meyerbeer)	Final scene
Curare /tubocurarine	“Il Guarany” (Gomes)	
Venon of snakes / neurotoxins	“Antony and Cleopatra” (Barber)	“Give me my robe”
?	“Mitridate, Re di Ponto” (Mozart)	“Ah ben ne fui presaga ... Pallid' ombre”
Arsenic trioxide	“Simon Boccanegra” (Verdi)	Poison scene (Act II)
Arsenic trioxide BAL and DMSA (agents for As(III) chelation therapy)	“Lucrezia Borgia” (Donizetti)	End of act I
Copper(II) arsenite (Scheele's green) / trimethylarsine	“Patiente” (Gilbert & Sullivan)	"Am I alone and unobserved?"
Radium(II) chloride	“Madame Curie” (Sikora)	

Supporting Information

Quiz with seven questions (and the respective answers) involving chemistry and opera.

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